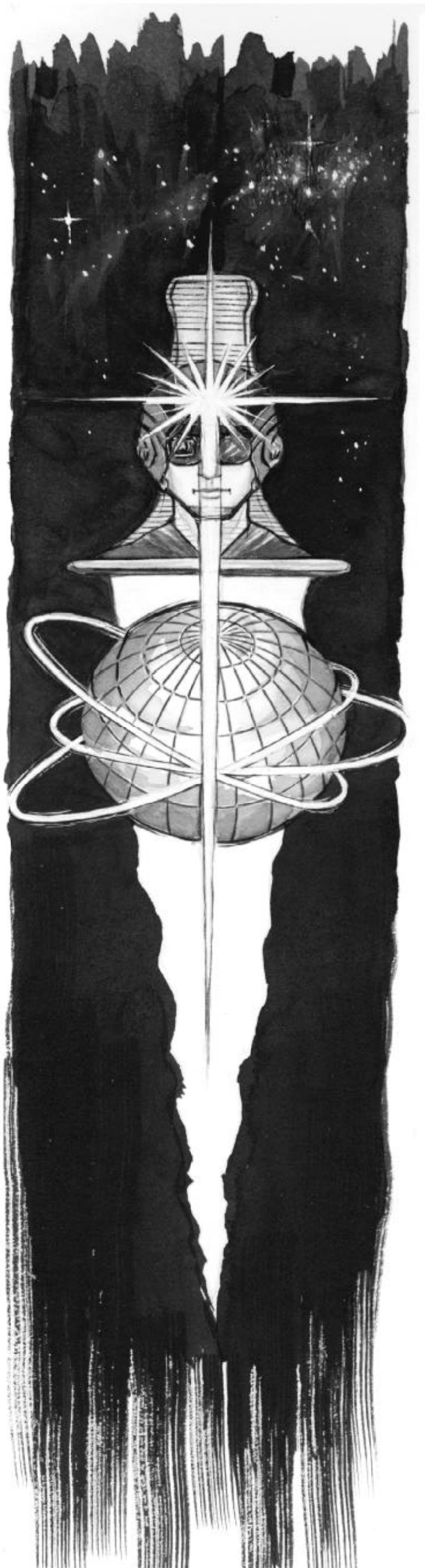


ANTIPODAL ZONES

Implications for the Future of Space Surveillance and Control

MAJ MARTIN E. B. FRANCE, USAF

MANKIND'S machines, his routes of travel and commerce, and the environment in which he has fought his wars were until relatively recent times confined to two dimensions that were restricted to the earth's surface—land and sea. During this long period, control of certain routes on land and sea have played critical roles in determining the wealth and power of nations. Napoléon said that the world could be his if only he had control of *La Manche* (the English Channel) for a day. The Fulda Gap, now a peaceful valley in central Germany, was once the focus of cold war land forces facing each other for over four decades. Critical choke points like the Suez and Panama Canals and the Straits of Gibraltar and Hormuz are so vital to world trade that the mere threat of closure incites talk of war. Enormous riches in the form of oil, raw materials, and finished goods pass through each daily. Russia's struggle for a warm-water port that would offer opportunities for trade, commercial development, and military power motivated the wars of Peter the Great as well as many of his successors, both imperial and communist.

Ideas about the supreme importance of the sea as a decisive factor in history as advocated by Alfred Thayer Mahan changed suddenly in the twentieth century when man first challenged the third dimension. Aircraft could now overfly the bottleneck and relieve the blockade, as in the Berlin airlift, or fly over the "Hump" to China. Aerial observation revolutionized battlefield intelligence for the commander, and the long-range bomber added a new aspect to strategic warfare. Air occupation of hostile territory was conjectured and applied, albeit with arguable success. The sea and land routes remained valuable, but the new dimension of airpower redefined our ideas of time, borders, and military strength.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Antipodal Zones Implications for the Future of Space Surveillance and Control**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air and Space Power Journal,155 N. Twining St,Maxwell AFB,AL,36112-6026**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The next logical step, space, had an impact at least as important as that of the airplane. Near-instantaneous worldwide communication, real-time imaging and surveillance, and the spectre of an unstoppable nuclear exchange with less than an hour's warning changed the world. Satellites have an operational lifetime of years instead of the hours of an aircraft mission. Once launched, they are difficult to detect and even more difficult to intercept or neutralize. Control and access to important land, sea, and air routes and the infrastructure are still vital to power and wealth. Today no nation or organization is capable of competing on the world stage without access to space assets. It's the ultimate high ground, but space systems have their vulnerabilities also, one ofwhich looks, at least at first glance, strikingly like an example of Mahan's proverbial narrow seas.[1]

The choke points of low-earth orbit, the antipodal zones, are of vital interest to the space user. A detailed understanding of what antipodal zones are, where they can be found, why they're important, and what we can do to exploit them is crucial to accomplishing aerospace control—a primary role of the US Air Force. This article provides that understanding as well as recommendations for both using antipodal zones to achieve aerospace control and mitigating our vulnerabilities to them.

Definition

The insertion of an artificial satellite into earth orbit requires a great deal of energy due to the earth's eastward rotation. This energy is needed to lift the satellite above the atmosphere and to accelerate it from its local, initial velocity on the launchpad to orbital velocities of greater than 7.5 kilometers (km) per second. Once this is done, the satellite will remain in orbit indefinitely, without any additional expenditure of energy, unless it comes into contact with the upper atmosphere.

Since the beginning of the space age, chemical rockets have launched every artificial satellite—manned and unmanned. While this is not the only way to space, it will almost certainly remain the method of choice for the foreseeable future. In terms of orbital analysis, a chemical rocket launch is very simple. Because of the short total engine burn time (10 minutes or less), the orbital insertion point is generally considered to be at the same longitude and latitude (but not altitude, obviously) as the launch site.

Once burnout occurs, if there are no other engine burns, the satellite will follow an elliptical path in a fixed plane that contains the insertion point and the earth's center and is parallel to the vehicle's position vector (fig. 1). Given the definition of the orbit shown in figure 1, one sees that regardless of the satellite's launch direction (i.e., the compass direction of its velocity vector at orbit insertion), all of the possible orbital planes contain a third critical point besides the earth's center and the launch point, defined here by the vector $-R_1$.

Figure 2 displays this same feature, but in terms of orbital ground tracks on a flat projection map for satellites launched into a 1,000-kilometer altitude orbit from

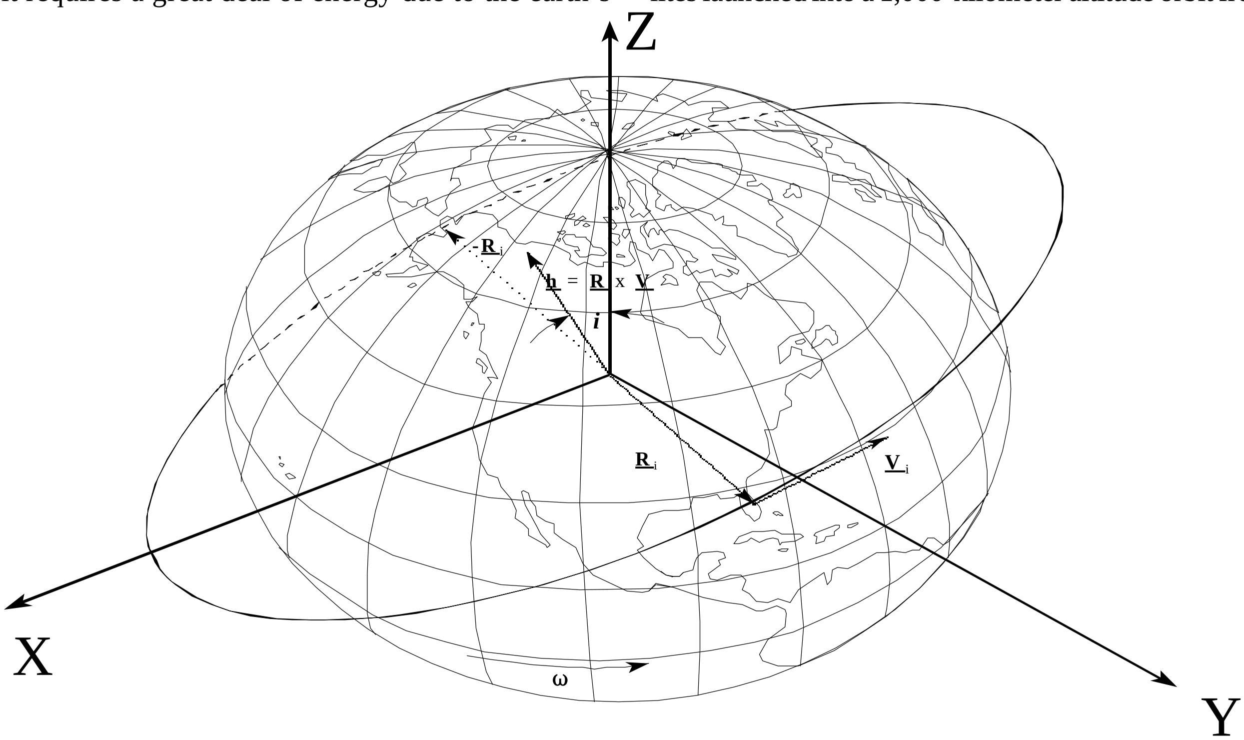


Figure 1 Orbital Geometry

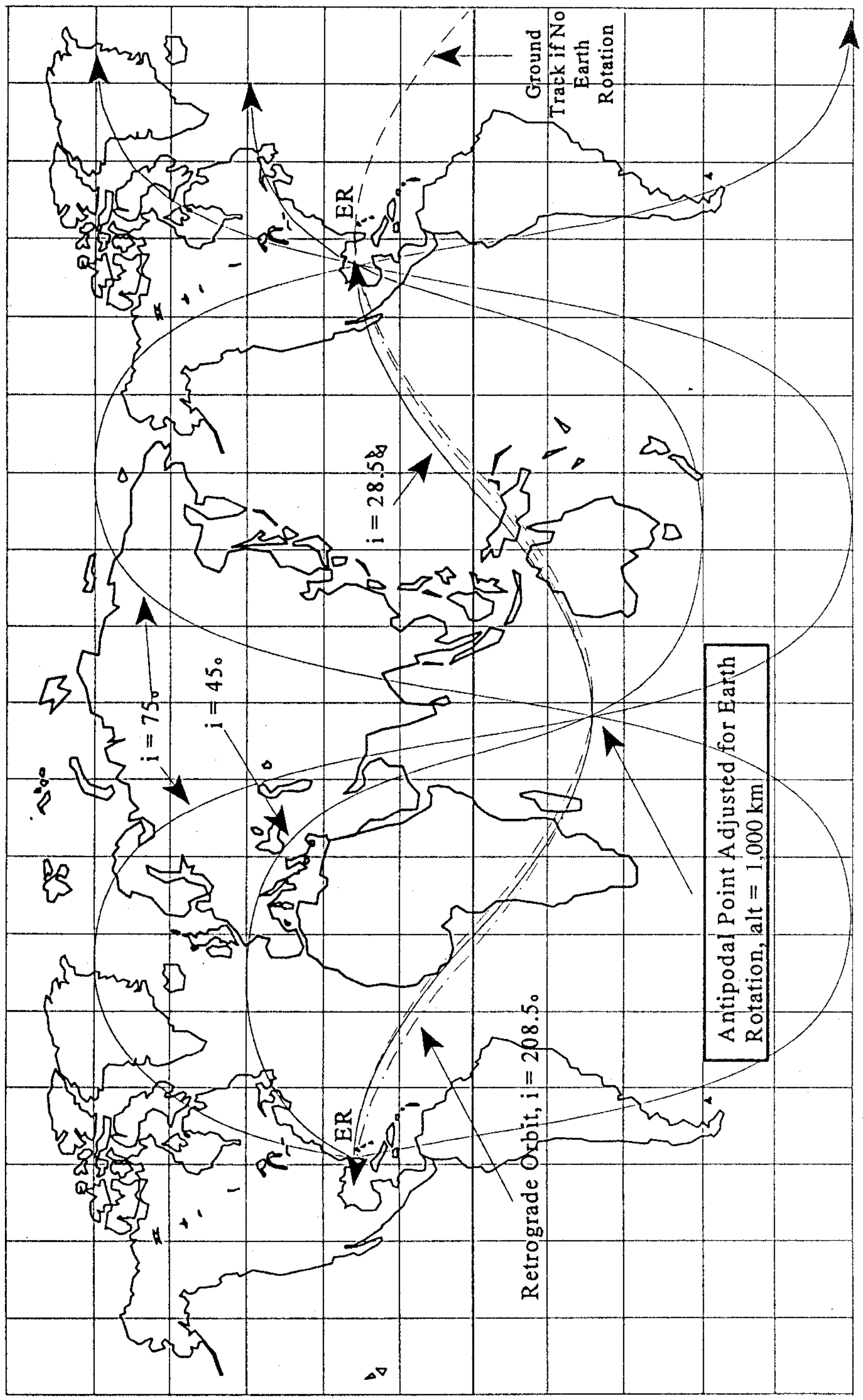


Figure 2. Orbital track Illustration (Adjusted antipodal point for Capte Canaveral; Altitude = 1000 kilometers)

Cape Canaveral. This third point—called the antipodal point—is located exactly opposite on the globe from the launch/orbital insertion point. We define an antipodal zone (AZ), then, as an area on the earth's surfacedirectly opposite from the orbital insertion points possible at a specified launch complex. When one takes into account the rotation of the earth under the satellite during the period in which the satellite travels from insertion to antipodal point (approximately 11 degrees of longitude for low earth orbit—LEO), the adjusted antipodal zone (AAZ) for a launch site will be centered somewhere near 11 degrees west of the launch site's antipodal point. Any satellite launched into LEO (an altitude less than 1,000 km) from Cape Canaveral will pass over its AZ provided the spacecraft performs no other orbital maneuvers in its first half-orbit. Therefore, if one is looking for the ideal point from which to observe any satellite launched into LEO from a specific spaceport, they need look no farther than the antipodal zone!

Implications and Significance

In the nineteenth century, Alfred Thayer Mahan's treatise, *The Influence of Sea Power upon History 1660–1783*, discussed naval blockades that contained the maritime threat posed by an enemy fleet (e.g., the simultaneous British blockade of Toulon, Brest, the coast along the Bay of Biscay, and Cadiz) [2] and the control of key straits that could effectively deny necessary commercial trade to colonial nations of the era. Today space control is defined as operations that ensure freedom of action in space for friendly forces while limiting or denying the enemy freedom of action in the use of its space systems during conflict. [3] Is it possible, then, to blockade space? Can we effectively deny an enemy's access to space in the early stages of a conflict or at any time our adversary attempts to deploy additional space assets, such as surveillance, communications, or orbital antisatellite (ASAT) vehicles?

The complexes capable of supporting a satellite launch are very well known. Several are located in littoral regions and could be neutralized by air or naval strikes using conventional munitions. Launch complexes are not currently heavily fortified, nor are the launch vehicles themselves able to absorb much damage. Other, possibly more important, launch sites, however, are located well inland and would require either a spaceborne intercontinental ballistic missile (ICBM) attack or an air strike involving a very long and dangerous overflight of enemy territory. In the latter case, it might be preferable to intercept the launched satellite after its postboost stage but before it is fully operational or has in fact completed its first orbit. Antipodal zones hold the key to this type of operation.

Once the launch sites are located, the associated antipodalzones are also known. For low earth orbits, then, the satellite will pass almost directly the AZ about 45 minutes after launch. In the antipodal zone, friendly space control assets can be brought to bear against the target to either intercept and, presumably, destroy it or to examine and characterize it via remote sensors, be they electromagnetic (radar) or optical (telescopes). These assets could be either ship-based or airborne, since the antipodal zones mentioned are over open oceans.

In short, antipodal zones can be thought of as the modern-day space equivalent of passes or straits. Control of these points, comparable to the control of naval choke points found in Mahan's theory, could effectively deny space access to others. Allowing others to control our antipodal zones could be a fatal mistake.

Interception

The first required task prior to interception or detection at an AZ is launch detection. Current Air Force Space Command (AFSPACECOM) assets such as Defense Support Program (DSP) satellites would certainly be responsible here since this is part of their current mission. Once alerted, components of the US Space Command's (USSPACECOM) space surveillance network could relay preliminary orbital element data to interceptors (air or sea) at the AZ. [4] Radar data at the antipodal zone would then provide additional data to facilitate the terminal phase of interception. Such a mission seems to fit a ship-based system because of the size of radar needed to detect the incoming satellite soon enough to allow interception. However, without some prior warning from DSP or another system as to the direction of the incoming satellite, interception by a sea- or air-launched missile could be quite difficult because of the speed of the target.

A kinetic-energy intercept has its disadvantages. Most notably, the explosive disintegration of an orbiting satellite can add literally thousands of potentially lethal pieces of debris, each traveling over 7.5 km per second. These pieces of space junk can become widely dispersed due to changes in each chunk's orbital elements from those of the original satellite caused by the explosion and natural orbital perturbations (such as solar and lunar gravity, earth's oblateness, solar pressure, and so on) that act on any orbital body. The net result may be the poisoning of an entire orbital belt—something we do not currently have the means of cleaning—making it useless or very dangerous for any assets, friendly or otherwise, that either traverse the belt

or operate in it. This poisoning would be minimized for low orbits below 500 km because atmospheric drag would cause the reentry of most debrisover time; above 500 km, however, the debris may stay in orbit for decades. AFSPACECOM currently tracks over 7,000 objects as small as 10 centimeters in LEO and one meter in geosynchronous earth orbit (GEO), although it has been estimated that there are 40,000 to 80,000 untrackable fragments in LEO down to one centimeter in diameter—nearly half of which are a result of nearly 100 satellite breakups since 1961.[5] Of course, any breakups caused by impacts with orbital debris would only serve to magnify the problem by producing even more high-speed space mines.

The use of a directed-energy weapon such as a laser would reduce necessary warning time even more because intercept occurs at the speed of light. In many cases, the chances of explosion and debris creation would also be reduced, but these benefits are tempered by the increased difficulty in assessing a target kill. Atmospheric conditions may also decrease the effectiveness of a laser, depending upon the wavelength chosen and the availability of adaptive optics necessary to compensate for atmospheric distortions of the beam.

What goes into LEOs and which of these satellites might be viable targets for antipodal-zone interception? Of primary military interest at low altitudes, high-resolution imaging satellites would probably be the first target of our proposed antipodal-zone interceptors. Signals and electronic intelligence (SIGINT, ELINT) satellites, responsible for eavesdropping on a potential adversary's radio traffic, might also be found at these altitudes.[6] The disabling of an enemy's space-based reconnaissance systems—engaged in both imaging and data collection—could effectively blind them during the critical early stages of an attack, especially in a situation in which friendly forces also have control of the airspace in the theater of operations, thus preventing aerial reconnaissance. In fact, the interception of newly launched platforms could even prevent an attack by making the enemy's chance of success too small to bear.

Fractional-orbit warheads—those that complete more than one-half but less than a full orbit prior to reentry and target strike—would also be vulnerable to antipodal-zone attack. The Soviet Union tested just such a system (a modified SS-9, Mod 3 Scarp)[7] in the 1960s. However, conventional ICBM and submarine-launched ballistic missile (SLBM) reentry vehicles, as well as intermediate-range ballistic missiles (IRBM) and theater ballistic missiles like the Scud, would not be vulnerable, since they reach their target in less than half an orbit (i.e., prior to passing over their launch site's antipodal point).

Problems with the Concept

Obviously, there exists a very important class of satellites that would seem to be vulnerable to early attack at antipodal choke points, but can this vulnerability be minimized or eliminated altogether by either a potential enemy or by American forces seeking to protect their space assets? Also, what types of satellites simply cannot be reached using this strategy due to their operational orbits? The latter question will be addressed first, continuing the discussion of satellite missions and their related orbits.

Three important classes of spacecraft are typically placed into orbits that do not lend themselves to antipodal-zone interception—commmunications, missile early-warning, and navigation satellites. Missile early-warning satellites, most current communications satellites, and many meteorological satellites are found in geosynchronous earth orbit. A satellite at GEO altitude (35,786 km) and zero inclination (i.e., the orbital plane lies in the earth's equatorial plane) rotates around the earth at precisely the same rate that the earth rotates about its axis. The result is a geostationary orbit (GSO), in which the satellite remains over the same spot on the equator, looking down over nearly half of the earth's surface. Three such satellites, appropriately spaced longitudinally, have worldwide coverage except for relatively small areas over the poles.

To put a satellite into GSO, the launch vehicle usually first inserts the spacecraft into LEO. As the satellite passes the equator, headed either northbound or southbound, an upper stage ignites, propelling the spacecraft into a geosynchronous transfer orbit (GTO). GTO is a highly elliptical orbit whose perigee (lowest altitude) is that of a typical circular LEO (e.g., 200 km) and whose apogee is at GEO altitude (35,786 km).

When the satellite reaches apogee, an integral upper stage or apogee kick-motor provides the necessary energy to circularize the orbit and change the inclination to zero degrees (fig. 3). This final maneuver is called a combined plane change, since the two thruster burns generally needed to circularize an elliptical orbit or to effect a plane change are combined into one. A GTO usually has the same inclination as the launch site's latitude—as is the case for a due-east launch that takes full advantage of the launch site's tangential velocity caused by earth's rotation. Like any satellite launched directly into orbit, one in GTO will pass over its antipodal point, since the thruster burn that moved it from LEO to GEO did not change the orientation of the orbital plane, only the size of the orbit. Unfortunately, because of the size (semimajor axis) of the or-

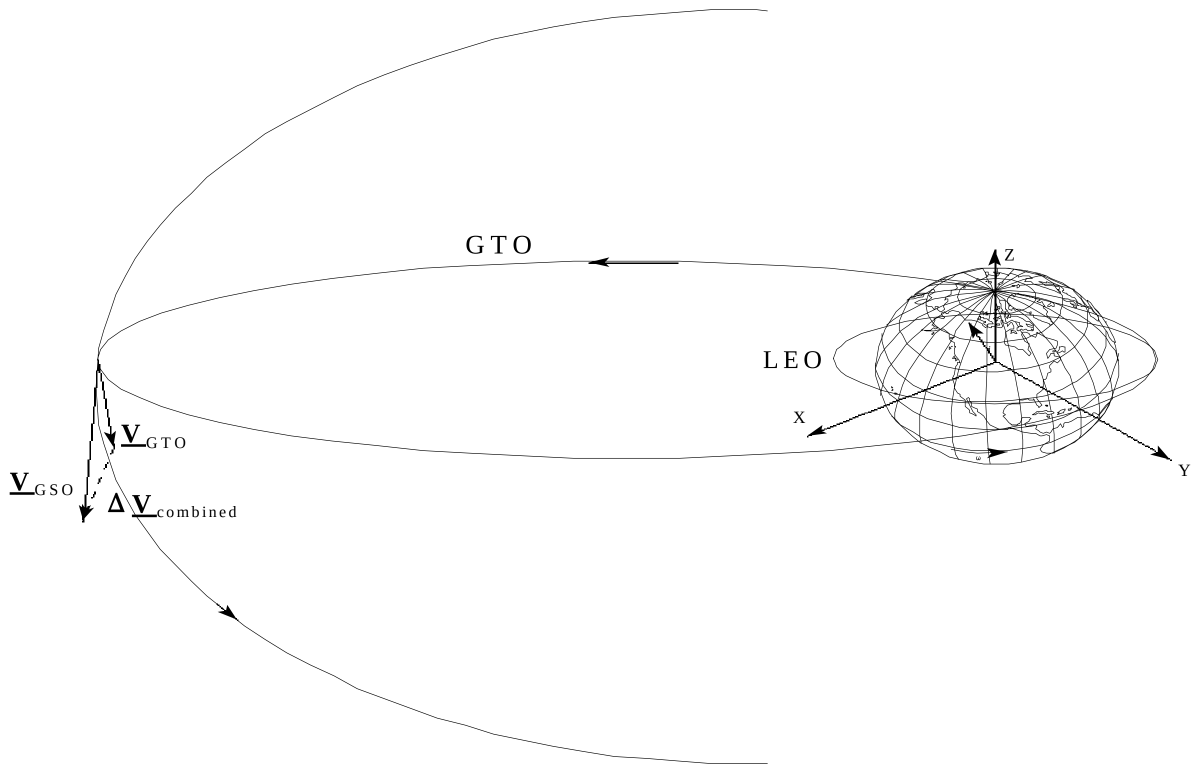


Figure 3. Combined Plane Change at Apogee of GTO

bit, the elapsed time to where thesatellite is directly over the launch site's antipodal point may be up to five hours. The earth may have rotated over 60 degrees in this time, much greater than the 11 to 13 degrees for LEO! Our intercepting platform, waiting at the LEO antipodal point will be nowhere near this point, and the rocket needed to intercept would be prohibitively large anyway, since the satellite's altitude would be much greater as well. If the optics problems due to beam propagation over such a large distance and through the atmosphere could be solved, however, laser interception might still be possible if we stationed our directed-energy weapon at an anticipated GTO antipodal point.

Other orbits above LEO that would cause similar problems for interception include those at semisynchronous (12-hour period) altitudes. Circular semisynchronous orbits are used by satellites in the GPS constellation, while Molniya orbits—inclined, highly eccentric, but still 12-hour orbits—are used by the Russians to provide communications support to high-latitude (polar) regions. In each of these cases, a prepositioned antipodal-zone LEO interceptor—particularly of the kinetic-energy kill variety—would be of little use. Figure 4 shows a comparison of the above orbits, while figure 5 shows the antipodal point for each orbit type (GPS, Molniya, and a first-chance GTO) projected onto the surface of the earth for a launch from the Russian complex at Tyuratam.

As another example, consider the case of a satellite launched directly east (minimum initial inclination) into GTO from the Xichang launch complex in China. If at the descending node a tangential thruster burn (i.e., in the same direction as the satellite's velocity vector, **V**) is accomplished resulting in a GTO, the satellite's ground track would pass no closer than 2,394 km from the launch antipodal point and approximately 1,000 km from the antipodal point adjusted for earth rotation (AAZ) at an altitude of 5,000 km. Because of this high altitude, however, line-of-sight contact would be possible from both points. Instead of the 44 minutes elapsed time from launch to antipodal (half-orbit) point typical of satellites in LEO, nearly 98 minutes will have passed.

A related weakness in the concept of antipodal interception is that posed by the orbital maneuvering capability possessed by many satellites besides those placed in GSO. The plane-change maneuver used to

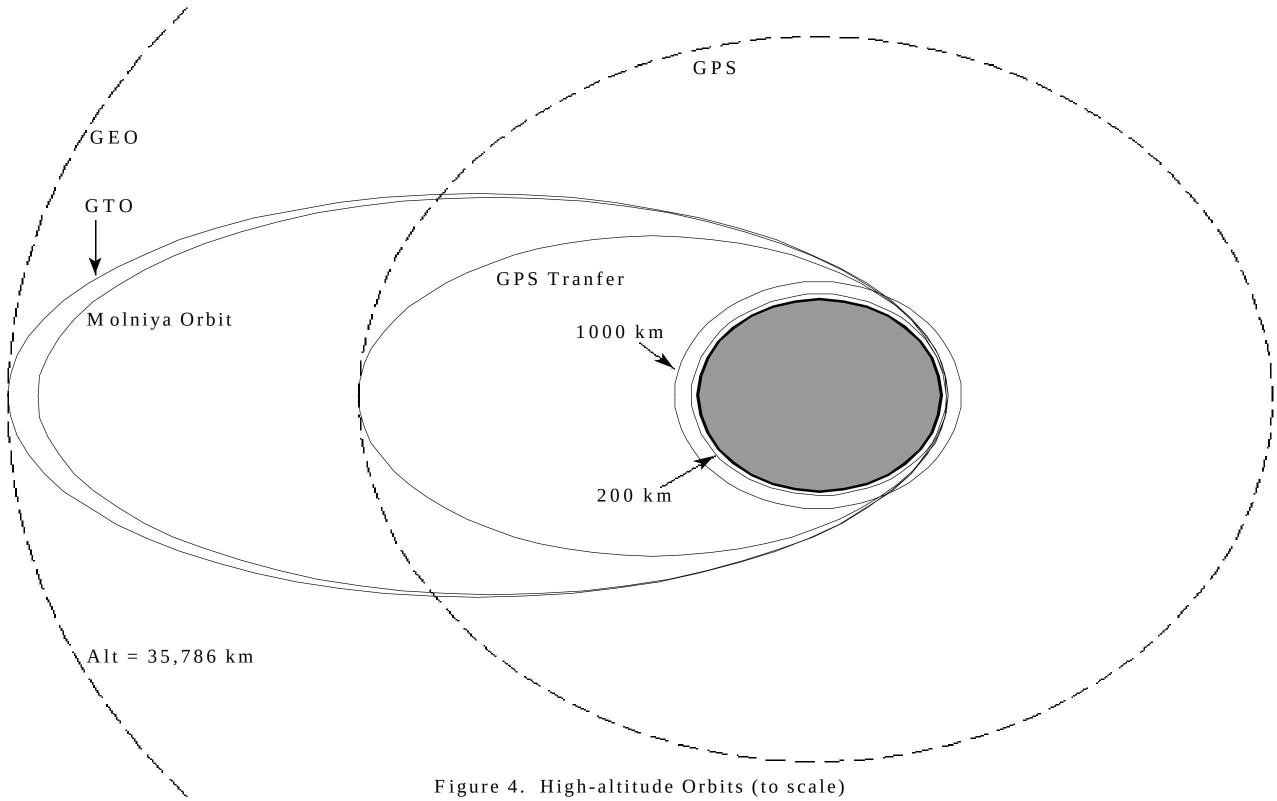
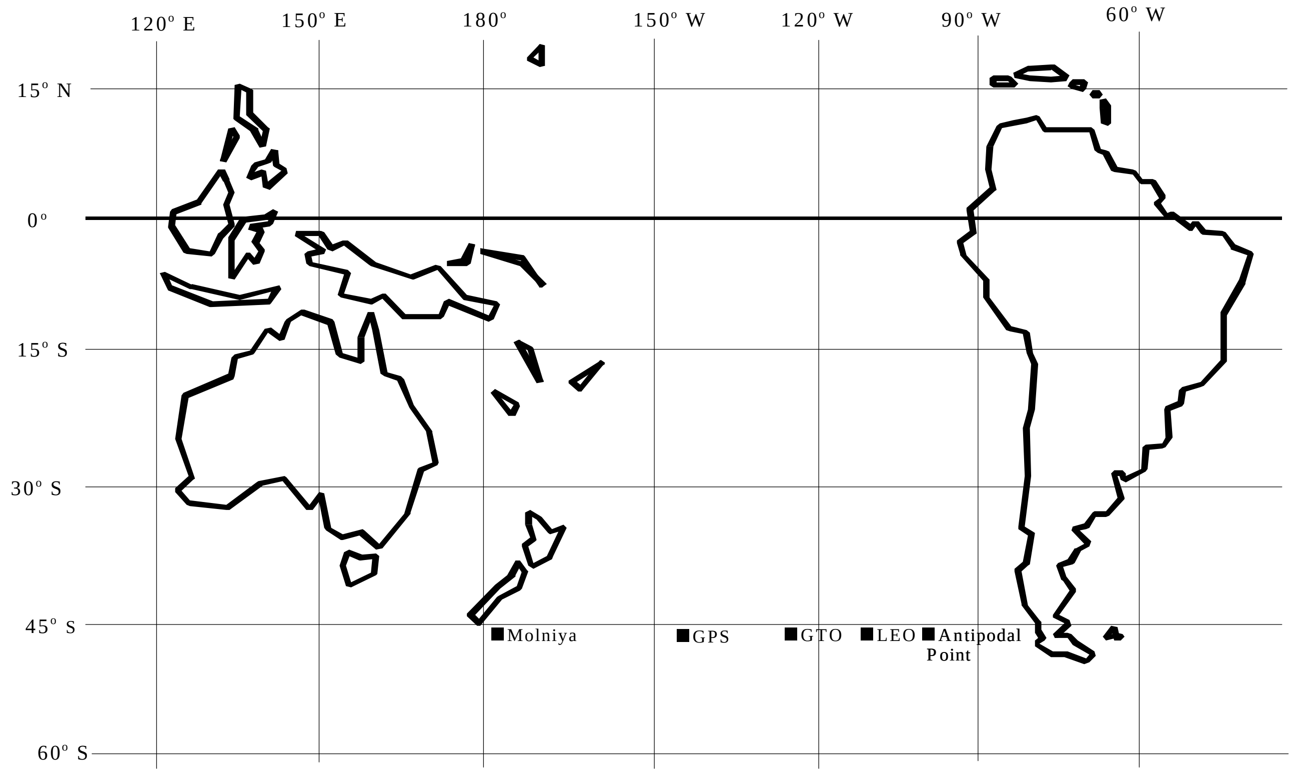


Figure 4. High-altitude Orbits (to scale)

zero the inclination of a satellite in GSO can be accomplished by any satellite. If, for example, a plane change is effected during the first half of a satellite's orbit using onboard thrusters or a strap-on upper stage at the descending node of a satellite launched from the northern hemisphere, the satellite may not pass over its launch site's AAZ. Most LEO satellites, however, are launched directly into their operational orbits to minimize useof onboard fuel and to maximize either payload or service life. Any fuel expended to accomplish evasive orbital maneuvers reduces fuel that otherwise would be used for on-orbit station keeping to counter orbital perturbations, maintain proper satellite attitude, or to power onboard systems. Still, because of the relatively low altitude involved, these maneuvers can take LEO satellites out of range (line-of-sight) for waiting AZ interceptors.

As an example, consider the case of a 1,000-kilogram reconnaissance satellite launched from Kourou, French Guiana, into a polar ($i = 90^{o}$) circular orbit at an altitude of 200 km. As it passes over the North Pole, the satellite fires an attached upper-stage thruster directed in such a way as to maximize the orbital plane change while keeping the circular orbit altitude constant. If the objective is to change the orbit sufficiently so that the satellite is out of the line-of-sight of a surface detection/interception station at the AAZ, there are several strap-on commercial upper stages that can easily achieve this level of performance.[8] Although the added weight would be expensive, it would by no means be prohibitive and would be well within the launch capability of an Ariane 4 rocket. Obviously, if an enemy is aware that his launch site's AZ is controlled by opposing forces for a specific orbit altitude, he can take substantial and fairly simple steps to bypass this choke point, much like an aircraft taking an alternate route to the target. The additional costs are real (between $5,000 and $50,000 per kilogram, depending upon the system used)[9] but not insurmountable, especially in situations where national security is involved.

Probably the most serious threat to this new strategy of orbital strangulation comes from the development of mobile launchers. The United States currently has one operational mobile launcher, the air-launched Pegasus rocket produced by Orbital Sciences Corporation. First launched in April 1990 from off the Pacific Coast near Monterey, California, Pegasus is a winged, three-stage, unmanned vehicle carried aloft by the same USAF-owned, NASA-operated B-52 (#0008) that was used to launch the X-15 in the early 1960s. Orbital Sciences has since acquired a Lockheed L-1011



for later launches, but the point remains that such a system could be flown to any point on the globe for launch.[10] The benefit for evading an antipodal-zone interception is obvious: Intercepting forces would not know the launch antipodal point until after the launch, greatly reducing the chances of having early-intercept assets on hand.

Taurus is another system produced by Orbital Sciences Corporation. This standard vertical-launch, four-stage vehicle uses the same first stage as the Peacekeeper missile. The upperthree stages are identical to the Pegasus rocket. What makes Taurus unique is its low-infrastructure launch capability. Originally contracted by the Defense Advanced Research Projects Agency (DARPA), Taurus is designed to place small satellites into LEO within 72 hours of command, following a five-day setup on a standard cement slab not unlike what could be found at any airport. The entire system is easily transportable to provide for wide deployment and surge launch capability.[11] Only very good intelligence gathering and mobile interceptors guarantee antipodal-point interception for a satellite placed into LEO by such a system.

Other future systems that could make antipodal-zone interception impractical are reusable launch vehicles (RLV) such as fully operational versions of the National Aeronautics and Space Administration (NASA) X-33 and X-34 RLV technology-demonstration programs. These systems may be self-ferrying and capable of operating at launch sites requiring little specialized support such as standard airport facilities or, in some cases, any flat piece of ground. Additionally, RLV systems are inherently more maneuverable than the standard direct-launch, expendable vehicles that have monopolized the launch industry since the days of Sputnik.

Whereas Pegasus is the only currently operational mobile launch system, there is little doubt that other nations have the technology available. For example, in 1991 Space Commerce Corporation proposed using SLBMs of the former Soviet Union to launch small payloads into LEO from Delta-class submarines. The Vysota (SS-N-8 Sawfly), Volna (SS-N-18 Stingray) and Shetal (SS-N-23 Skiff) could all launch satellites into orbit with no more warning than an SLBM attack and, of course, very little time to position forces in the correct location to make antipodal-zone interception practical.[12]

The fact that mobile launch systems are not more common is probably due to the increased cost of development (in some cases) and the reduced payload over medium- and heavy-lift vehicles that currently operate from fixed, high-infrastructure sites. Also, no real threat of antipodal-zone interception has necessitated a hard look at the advantages of such a mobile system. However, if such a threat materializes, mo-

bile systems will quickly become the norm, in much the same way that mobile ICBMs and IRBMs were considered quite seriously and in some cases fully developed during the cold war in response to the increased threat of counterforce targeting. Of course, SLBMs have always been mobile in this sense.

Alternatives

The question of which type of ASAT system would best serve the mission of space control is quite complex, and has already filled volumes—from studies to proposals, actual tests, and endless debate. The intention here is not to fully cover this subject but to suggest where antipodal-zone interception concepts might (or might not) fit into this debate.

Of course, an ASAT system would have some commonality with a ballistic missile defense (BMD) system and would in many cases be completely redundant. For example, a boost-phase (prior to orbital insertion) interception system would be equally as effective for negating a reconnaissance satellite launch as that of an ICBM. Space-based interceptors that could neutralize ICBM or SLBM reentry vehicles in the midcourse phase could also intercept satellites—particularly those in LEO. DSP satellites and other launch-detection assets mentioned earlier would provide launch warning for both system types. For these reasons, it would seem obvious that if the United States were to develop and deploy a boost or midcourse-interception BMD system, there would be little reason to develop an additional ASAT system based on antipodal-zone interception, although surface-based components of this type of system (directed-energy weapons, for example) could be deployed in critical AAZs during times of heightened tension.

A terminal-phase BMD system using kinetic interceptors might be employed in an AZ-interception scheme, assuming they had the altitude capability necessary for LEO intercept. However, deploying such a system for long periods of time in the open ocean would be expensive and difficult, especially since such a shipborne asset would be an attractive target to any enemies intent on preserving their space accessibility. A ship-based interceptor would presumably require the type of protection one would associate with a carrier battle group. Loiter time of an airborne intercept, or detection system at an antipodal point would be even more limited, and the distance of most AAZs from land would make ground-based, rapid-response, or alert aircraft ineffectual.

Still another argument against the necessity of placing interception assets in AAZs is the fact that any satellite launched into LEO will pass within line of sight and therefore presumably be within interception range, at least once per day, for any ground-based interception site located at a latitude less than or equal to the satellites inclination. In other words, we could intercept any satellite in LEO within 24 hours, using the same assets that an antipodal-zone system would use, from the safety and security of the continental United States (CONUS). The maximum wait time would be much less with additional assets based in several widely dispersed locations such as Hawaii and Diego Garcia. Considering the fact that the United States has already successfully tested an air-launched (from an F-15) ASAT against a target in LEO during the 1980s—though it was never operational—argues against the necessity of investing in an antipodal-zone interception system.

Conclusion

This paper has defined antipodal-zone interception of space assets in the context of modern space-control strategy without real regard to national policy or whether any ASAT system should be deployed. The point was not to argue if ASAT systems should be used, but simply to point out that certain operational and strategic objectives could be met through their employment, in times of crisis, if the necessary system infrastructure is present and the national command authorities decide to use them. Like any militarily significant technical advancement, the use of space assets to advance or secure national power in the context of the modern world will not be forgotten. In this grand strategy that aims primarily at access to or denial of vital information—command, control, communications, information, and reconnaissance sys tems—antipodal-zone interception of just-launched space assets constitutes an aspect of space control that both we, the United States, and our contemporaries in the space-faring world must recognize and exploit if possible and economically justifiable. The United States should continue to develop space launch systems that are relatively invulnerable to AZ interception, such as Pegasus, Taurus, RLV, and others, while maximizing launch flexibility and surge rates and minimizing necessary launch infrastructure and, therefore, cost. Designing for additional orbital-maneuvering capability in future high-value spacecraft would also minimize our vulnerability to AZ-based ASAT weapons systems. If adversaries develop AZ-interception capability, above and beyond any based on their own soil, US naval or air assets should be trained and employed to neutralize the threat, if necessary, in times of heightened tension or outright conflict.

Because of the many available counters to AZ in-

terception, however, and the fact that cheaper and, in some cases, proven tactics already exist for ASAT operations, the United States should not pursue development or further study of an antipodal-zone interception system. It should not do this for reasons stated in the body of this paper—namely, that any interceptor technology developed for AZ use would almost certainly be just as effective, and in many cases no slower, if based within the borders of the United States, its possessions, or those of its allies. The priceof a durable, persistent AZ-based system would almost certainly be much higher, however, because of the location of AZs of potential adversary nations. AZ basing would, again, be unnecessary and ineffectual if an enemy decided to employ evasive tactics or to develop mobile systems, as he most surely would if we had demonstrated control of the air and space above his launch site AAZs.

In conclusion, antipodal-zone interception is an interesting idea that deserved a complete evaluation. Awareness of any developments in ASAT technology in the future and being vigilant to threats they pose will continue to be important to the Air Force mission of space control. If used in conjunction with AZ control or basing, within a doctrine of generally minimizing the threat to our space assets, the relatively little leveraging such basing provides does not justify the expense to put them there.

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